Esterolytic Catalyses by Triazoles

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Abstract: The catalytic effects of 1,2,4-triazole, 1,2,3-triazole, and several of their respective derivatives in the solvolyses of neutral, negatively and positively charged phenyl esters were investigated. Similar studies were performed with poly-3-vinyl-1,2,4-triazole. For all systems it was observed that their catalytic effect exhibited a linear dependence on the concentration of their respective anionic forms. A comparison of catalytic behavior of the triazole and imidazole systems was made. The difference of their respective catalytic behavior was shown to arise from their pK_a values rather than the nature of the catalyzing species. An empirical relationship between catalytic ability and pK_a value can be expressed by the equation $\log k_i = n\text{p}K_i + \log C$, where n and $\log C$ are 0.612 and -2.97, respectively. This equation could possibly be used to predict the catalytic effect of a closely related five-membered nitrogen heterocycle.

In several examples, the reactions of synthetic polymers which contained both charged groups and catalytic functions have shown higher reactivities than those of their respective monomeric analogs.[2,3] Such effects are particularly evident in polymers which contain pendent imidazole groups.[2] It was expected from the similarity in structure of imidazole and 1,2,4-triazole, that poly-3-vinyl-1,2,4-triazole would perhaps show enhanced catalytic effects compared to its monomeric analog 1,2,4-triazole if similar cooperative interactions proposed for poly-4(5)-vinylimidazole[2,4] are also operative in the poly-3-vinyl-1,2,4-triazole system. Furthermore, the reported catalytic effect of 1,2,4-triazole in peptide syntheses[5,6] provided much hope in such an expectation.

Results and Discussion

Studies of the solvolytic reactions of the neutral ester *p*-nitrophenyl acetate (PNPA) catalyzed by 1,2,4-triazole and by poly-3-vinyl-1,2,4-triazole were undertaken in 28.5% ethanol–water solution at 26° and with an ionic strength, μ, of 0.02 *M*.

A study of the dependence of solvolytic rate on poly-3-vinyl-1,2,4-triazole concentration revealed that the catalytic rates for the solvolyses of PNPA were directly proportional to the polymer concentration. Similarly, it was shown that the reactions catalyzed by 1,2,4-triazole were also linearly related to the catalyst concentration. Although both of these processes are second-order reactions, it appears that at pH 8, the polymer is a less efficient catalyst than its monomeric analog. A similar situation, however, has previously been found for the solvolyses of PNPA catalyzed by poly-4(5)-vinylimidazole and imidazole, where at pH values below 7.5 the polymer was a less efficient catalyst than imidazole.[2]

In order to study in more detail the characteristics of poly-3-vinyl-1,2,4-triazole and 1,2,4-triazole catalyzed reactions, the solvolyses of neutral, anionic (sodium 3-nitro-4-acetoxybenzenesulfonate, NABS, and 3-nitro-4-acetoxybenzoic acid, NABA) and cationic (3-acetoxy-N-trimethylanilinium iodide, ANTI) substrates were investigated over a range of pH values. In the solvolysis of the neutral ester PNPA in the pH region 7–9, instead of observing an enhancement of the polymeric reaction rate as was expected from analogous studies of poly-4(5)-vinylimidazole, a reduced catalytic effect was observed in comparison with its monomeric analog 1,2,4-triazole (Figure 1).

Poly-3-vinyl-1,2,4-triazole was found to be a much poorer catalyst than 1,2,4-triazole even at high pH values. In fact, for the solvolysis of PNPA, 1,2,4-triazole was found to have a second-order catalytic rate constant (k_{cat}) approximately 50% greater than that of poly-4(5)-vinylimidazole at pH 9 under similar experimental conditions.[2,4]

The ineffectiveness of poly-3-vinyl-1,2,4-triazole as a catalyst was also revealed in the solvolyses of both negatively charged substrates NABA and NABS and the positively charged substrate, ANTI. At each pH value investigated, it was found that 1,2,4-triazole was a more efficient catalyst than poly-3-vinyl-1,2,4-triazole in the solvolyses of all the substrates studied (Figure 1).

Furthermore, no distorted bell-shaped pH–rate profile was observed for the poly-3-vinyl-1,2,4-triazole catalyzed solvolysis of NABS in the pH region where the polymer was partially protonated and the substrate was completely anionic, *i.e.*, between pH 1.7 and 4.1; in fact, no measurable rate could be detected in this pH region. Such an effect has been reported for several polymeric systems whereby the partially protonated sites on the polymer chain accumulate the anionic substrate into a high concentration of neutral, catalytically active function.[2–4] It is indeed surprising that no selective catalysis, *i.e.*, enhanced reaction rates, was found for any of the polymeric reactions. Although polymeric systems can be less efficient catalysts than their monomeric analogs, particularly with neutral substrates, they usually exhibit marked selectivity toward substrates which carry an opposite charge to that of the charged group on the polymer chain. This type of cationic–neutral interaction was obviously not noted in the poly-3-vinyl-1,2,4-triazole system.

Upon inspection of Figure 1, it is noted that there is an increased reaction rate for the 1,2,4-triazole and the

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(1) Abstracted from the Ph.D. Thesis of P. S. Yuen, University of Michigan, 1968.

(2) C. G. Overberger, T. St. Pierre, N. Vorchheimer, J. Lee, and S. Yaroslavsky, *J. Amer. Chem. Soc.*, 87, 296 (1965).

(3) R. L. Letsinger and T. J. Savereide, *ibid.*, 84, 3122 (1962).

(4) C. G. Overberger, H. Maki, and J. C. Salamone, *Svensk Kem. Tidskr.*, 80, 156 (1968).

(5) H. C. Beyerman and W. Maassen Van den Brink, *Proc. Chem. Soc.* (London), 266 (1963).

(6) H. C. Beyerman, W. Maassen van den Brink, F. Weygand, A. Prox, W. Konig, L. Schmidhammer, and E. Nintz, *Rec.*, 84, 213 (1965).

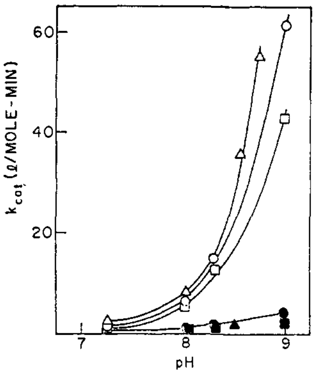

Figure 1. pH-rate profiles for the solvolyses of PNPA (○, ●), NABS (□, ■), and ANTI (△, ▲) catalyzed by 1,2,4-triazole and poly-3-vinyl-1,2,4-triazole, respectively; in 28.5% ethanol-water, ionic strength 0.02 *M*, 26°.

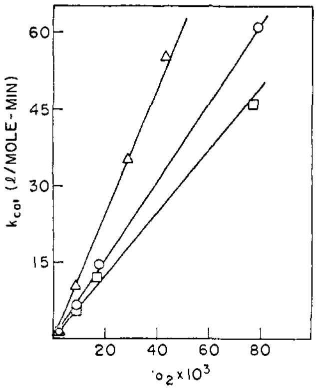

Figure 2. α_2-Rate profiles for the solvolyses of PNPA (○), NABS (□), and ANTI (△) catalyzed by 1,2,4-triazole; in 28.5% ethanol-water, ionic strength 0.2 *M*, 26°.

polymer-catalyzed reactions as the pH of the solution is increased, the 1,2,4-triazole reaction being increased to a greater extent. Such phenomena are reminiscent of the pendent benzimidazole-catalyzed reaction of PNPA, NABS, and NABA (3-nitro-4-acetoxybenzoic acid) where it was reported that these reactions at high pH values involved the participation of anionic functions in a cooperative interaction with neutral functions.[7]

If there are any cationic–neutral, neutral–neutral, or anionic–neutral interactions, such as proposed for poly-4(5)-vinylimidazole, poly-4-vinylpyridine, and poly-5(6)-vinylbenzimidazole,[2,3,7,8] operative in the poly-3-vinyl-1,2,4-triazole catalyzed reactions, then it would be expected that poly-3-vinyl-1,2,4-triazole would show some enhanced catalytic effects with one of the four substrates. Since no such bifunctional interactions are indicated with poly-3-vinyl-1,2,4-triazole, the catalytic process may involve either a cationic, neutral, or anionic 1,2,4-triazole participation.

At pH 7.25, 1,2,4-triazole, though a better catalyst than poly-3-vinyl-1,2,4-triazole, is not a particularly efficient catalyst. Calculations of the fractions of neutral 1,2,4-triazole (α_1) based on the pK_1 value of 2.28 showed that $\alpha_1 = 1$ at pH 6.3. At pH 7.25, almost all of the 1,2,4-triazole species are still in the neutral form, but on the anionic side of the isoelectric point. As the pH value is increased beyond the isoelectric point, the fraction of neutral 1,2,4-triazole species will obviously decrease, since there will be an increase in the anionic species. Therefore, for all the substrates studied, the neutral 1,2,4-triazole species could not be responsible for the drastic increase in catalytic rates as the pH is increased from 7 to 9.

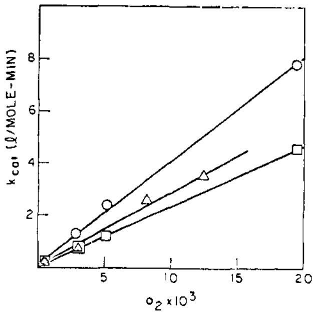

Figure 3. α_2-Rate profiles for the solvolyses of PNPA (○), NABS (□), and ANTI (△) catalyzed by poly-3-vinyl-1,2,4-triazole; in 28.5% ethanol-water, ionic strength 0.02 *M*, 26°.

The observed catalytic effect of 1,2,4-triazole could apparently be accounted for by the anionic 1,2,4-triazole species. If this assumption is true, then a linear relationship between the second-order rate constant, k_{cat}, and the anionic fraction of 1,2,4-triazole species, α_2, should be obtained. Indeed, such a linear relationship was obtained for 1,2,4-triazole catalyzed solvolyses of PNPA, NABS, and ANTI (Figure 2).

Since pendent, neutral–neutral, and anionic–neutral interactions are believed to be unlikely for the poly-3-vinyl-1,2,4-triazole catalyzed solvolyses of all the substrates studied, and the neutral pendent 1,2,4-triazole functions are as inefficient as those of neutral 1,2,4-triazole species, it would appear that the mechanisms of catalyses by the polymer are analogous to those of 1,2,4-triazole. Indeed, a linear relationship was found between k_{cat} and α_2 for the poly-3-vinyl-1,2,4-triazole catalyzed solvolyses of all the substrates (Figure 3).

Poly-4(5)-vinylimidazole[2] and poly-4-vinylpyridine[3] both were found to be less selective catalysts in the solvolyses of NABS when the pendent groups were almost neutral, while enhanced catalytic effects were observed when the polymers were partially protonated. Therefore, 1,2,4-triazole and poly-3-vinyl-1,2,4-triazole were studied with NABS at pH 1.7 and 2.0, a pH region in which the 1,2,4-triazole functions are partially protonated. It was found that they were both equally inefficient catalysts under these conditions, and the catalytic rates of these solvolytic reactions were negligible. These observations ruled out the possibility of a cationic–neutral interaction in the solvolysis of NABS catalyzed by poly-3-vinyl-1,2,4-triazole, and also eliminated the possibility of a cationic species participation in the solvolytic reactions catalyzed by the 1,2,4-triazole system. Since the second-order catalytic rate constants appear to be dependent only upon the fraction of the anionic 1,2,4-triazole species, α_2, the second-order rate constant can be explicitly represented as

$$k_{cat} = k_2\alpha_2 \qquad (1)$$

(For a detailed derivation of eq 1, see ref 2.)

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(7) C. G. Overberger, T. St. Pierre, and S. Yaroslavsky, *J. Amer. Chem. Soc.*, 87, 4310 (1965).

(8) C. G. Overberger, T. St. Pierre, C. Yaroslavsky, and S. Yaroslavsky, *ibid.*, 88, 1184 (1966).

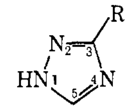
When the catalytic effects or activities of poly-3-vinyl-1,2,4-triazole and 1,2,4-triazole are compared directly, the substituent effect of the polymer chain on the 1,2,4-triazole ring is tacitly neglected. In such a direct comparison, it is assumed that the catalytic effect of any three-substituted 1,2,4-triazole would be solely dependent upon the concentration of the anionic species, *i.e.* the pK_2 value alone, at any pH value. Upon this assumption 3-methyl- and 3-isopropyl-1,2,4-triazole would have comparable catalytic effect, since their pK_2 values are 10.85 and 10.82, respectively. Kinetic studies revealed that 3-methyl-1,2,4-triazole was found invariably to be a more efficient catalyst then 3-isopropyl-1,2,4-triazole (Table I).

Table I. Second-Order Catalytic Rate Constants of 3-Methyl- and 3-Isopropyl-1,2,4-triazole for the Solvolyses of PNPA, NABS, and ANTI[a]

	k_{cat} (l./(mol min))		
Substrate	1,2,4-Triazole	3-Methyl-1,2,4-triazole	3-Isopropyl-1,2,4-triazole
PNPA	61.24	8.94	3.60
NABS	45.40	7.76	2.00
ANTI	55.10	16.00	14.50

[a] At pH 8.80 in 28.5% ethanol-water solution, μ = 0.02 *M*, at 26°.

The fact that 3-methyl-1,2,4-triazole is a better catalyst than 3-isopropyl-1,2,4-triazole suggests that in addition to the p*K* effect, a steric effect is involved in these solvolytic reactions. It has been shown by the general character of substitution reactions at position 1, and by dipole moment determinations of 1,2,4-triazole and its derivatives, that the active hydrogen is most likely located at position 1.[9] It is clear from the structural formulae of three-substituted 1,2,4-triazoles that the nitrogen atoms at positions 2 and 4 are subjected to steric hindrance, and that the isopropyl derivative is more hindered than the methyl derivative. When the respective compounds are in their anionic form, it is reasonable to consider that the nitrogen atoms at positions 2 and 4 also carry some negative charge, and that they, too, participate to a certain extent in the solvolytic processes. Thus, the greater steric hindrance experienced by positions 2 and 4 in 3-isopropyl-1,2,4-triazole may be the reason that renders 3-methyl-1,2,4-triazole a better catalyst than the former, even though they have comparable pK_2 values. This steric hindrance may in part be responsible for the reduced catalytic ability of poly-3-vinyl-1,2,4-triazole in comparison to 1,2,4-triazole and its three-substituted derivatives. However, the increased apparent pK_2 value of the polymer appears to be the major factor for such a behavior. We would like to point out here that we have no information concerning the conformational change of the polymer with variation of pH values at this time.



R = CH_3–, $(CH_3)_2CH$–

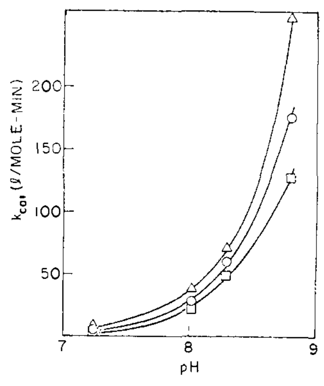


Figure 4. pH-rate profiles for the solvolyses of PNPA (○), NABS (□), and ANTI (△), catalyzed by 1,2,3-triazole; in 28.5% ethanol-water, ionic strength 0.02 *M*, 26°.

It has also been found that poly-2-vinylpyrrole, poly-2-vinylimidazole, and poly-2-methyl-N-vinylimidazole[10] showed no significant catalytic activities under the solvolytic conditions which were studied. Steric hindrance of the nucleophilic positions could be a major factor for this lack of catalytic activity, since in each case the substituent (polymer chain) is adjacent to the active center.

Since the catalytic activity of 1,2,4-triazole (pK_2 = 10.28) is apparently due to its anionic species, it would be expected that participation of the anionic species would also be operative in the 1,2,3-triazole (pK_2 = 9.50) system.

The studies of the dependence of the solvolytic rates of PNPA on 1,2,3-triazole concentrations revealed linear relationships, an indication that these are overall second-order reactions.

In the study of the solvolyses of PNPA, NABS, and ANTI by 1,2,3-triazole over the pH range 7.25–8.80 (Figure 4), drastic increases in the catalytic rates were observed as the pH was increased.

When the second-order catalytic rate constants, k_{cat}, were plotted against α_2, linear relationships were indeed obtained for each substrate investigated (Figure 4). These results indicate that 1,2,3-triazole is more efficient for the solvolysis of ANTI, less efficient for PNPA, and least efficient for NABS. These observations are consistent with the fact that the anionic 1,2,3-triazole species is responsible for these solvolytic processes, since ANTI would be electrostatically attracted by the anionic species, while NABS would be repelled and PNPA would experience no such electrostatic effect. This trend was also observed with 1,2,4-triazole (Figure 2).

Similar results were also obtained for 4-methyl- and 4-isopropyl-1,2,3-triazole. Since the steric effect of the 4 substituent could not extend to positions 1 and 2, then the pK_2 value would be the sole factor responsible for the observed catalytic effects. Indeed, 4-methyl and 4-isopropyl-1,2,3-triazole, which have an identical pK_2 value (10.25), showed almost the same catalytic effects (Figures 5, 6). A study of 1,2,3-benzotriazole (pK_2 = 8.65) showed similar results (Figure 7).

Studies of the catalytic effects of imidazole, 1,2,4-triazoles, 1,2,3-triazoles, and 1,2,3-benzotriazole in the solvolyses of the substrates studied indicated that their catalytic activities are related to their pK_1 or pK_2 values.

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(9) I. B. Mazheika, G. I. Chipen, and S. A. Hiller, *Chem. Hetero. Compd.*, 2, 600 (1966).

(10) (a) A. Wartman, M.S. Thesis, Polytechnic Institute of Brooklyn, Brooklyn, N. Y., 1967; (b) C. G. Overberger, in preparation.

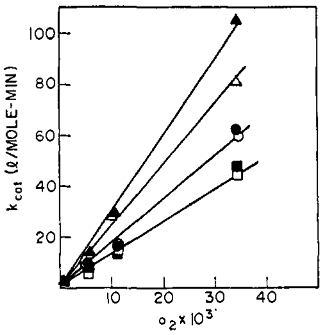

Figure 5. k_{cat}–α_2 profiles for the solvolyses of PNPA (○, ●), NABS (□, ■), and ANTI (△, ▲) catalyzed by 4-methyl-1,2,3-triazole and 4-isopropyl-1,2,3-triazole, respectively; in 28.5% ethanol-water, ionic strength 0.02 *M*, 26°.

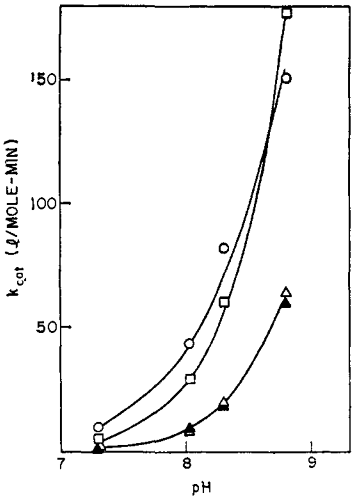

Figure 6. pH–rate profiles for the solvolyses of PNPA by 1,2,3-triazole (□), 4-methyl-1,2,3-triazole (▲), 4-isopropyl-1,2,3-triazole (△), and 1,2,3-benzotriazole (○) in 28.5% ethanol-water, ionic strength 0.02 *M*, 26°.

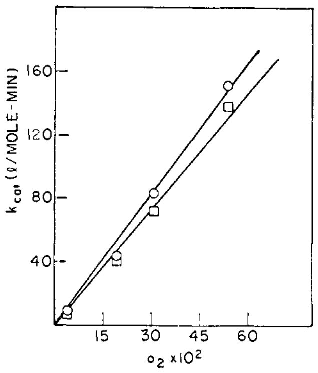

Figure 7. α_2–rate profiles for the solvolyses of PNPA (○) and NABS (□) catalyzed by 1,2,3-benzotriazole; in 28.5% ethanol-water, ionic strength 0.02 *M*, 26°.

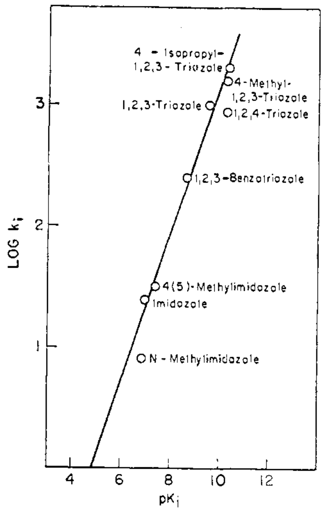

Figure 8. Dependence of catalytic rate on p*K* value.

A relationship of this type has been described by Brønsted where the logarithm of the catalytic rate constant is proportional to the pK_a values of the base,[11] which has been demonstrated by Jencks and Carrivolo in their studies with PNPA.[12]

The second-order catalytic rate constants (k_{cat}) thus far obtained for the imidazole[2,4,7,8] and triazole systems are related to the total concentration of the catalysts, and not to the concentration of the catalytically active species. Therefore, in order to consider a relationship between the catalytic abilities of the various catalysts, the corrected second-order catalytic rate constants should be used, *i.e.*, k_{cat} has to be corrected by a factor of $1/\alpha_i$ where α_i is the fraction of the catalytically active species present in any pH. We could then define k_i, the corrected second-order catalytic rate constant in the following manner, $k_i = k_{cat}/\alpha_i$ where $i = 1$ or 2 for the neutral or anionic species, respectively.

The neutral substrate PNPA would be the best system to study for a consideration of the relationships between k_i and pK_i values because electrostatic effects are unlikely. The corrected second-order catalytic rate constants k_i are summarized in Table II. Poly-3-vinyl-1,2,4-triazole, 3-methyl-, and 3-isopropyl-1,2,4-triazole are not considered, since steric factors are involved in their solvolytic reactions.

Table II. Corrected Second-Order Catalytic Rate Constants for the Solvolyses of PNPA[a]

Catalyst	*i*	k_i, l./(mol min) (average)	pK_i	No. of runs
1,2,4-Triazole	2	825.0	10.28	7
1,2,3-Triazole	2	998.0	9.50	7
4-Methyl-1,2,3-triazole	2	1570.0	10.25	7
4-Isopropyl-1,2,3-triazole	2	1629.0	10.25	7
1,2,3-Benzotriazole	2	247.0	8.65	7
4(5)-Methylimidazole	1	32.0	7.40	4
Imidazole	1	24.3	6.95	*b*
N-Methylimidazole	1	8.2	6.92	*b*

[a] In 28.5% ethanol-water and $\mu = 0.02$ *M*. [b] Values obtained from ref 2 and 8.

A linear relationship was realized when log k_i was plotted against pK_i (Figure 8). These findings indicate that the catalytic activity of a species is solely dependent upon its pK_i value and not on the nature of such species, *i.e.*, if an imidazole compound has a pK_1 of 9.50, then its neutral species would have the same catalytic

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(11) T. C. Bruice and S. J. Benkovic, "Bioorganic Mechanisms," W. A. Benjamin, Inc., New York, N. Y., 1966, Chapter 1.

(12) W. P. Jencks and J. Carrivolo, *J. Amer. Chem. Soc.*, **82**, 1778 (1960).

activity as the anionic 1,2,3-triazole species at any pH; conversely, we could predict that anionic tetrazole (pK_2 = 4.89[13]) would exhibit a k_2 of 1 l./(mol/min) in the solvolysis of PNPA. Similarly, the neutral species of pyrazole (pK_1 = 2.53[14]) would also be a poor catalyst for such reactions, and a k_1 of less than 1 l./(mol min) is predicted. Therefore, the nature and activity of a five-membered nitrogen heterocycle could apparently be predicted to a certain degree in ester solvolyses when no steric factor is involved. This k_i and pK_i relationship could be expressed in the following empirical equation

$$\log k_i = np K_i + \log C \qquad (3)$$

where both C and n are constants; n and $\log C$ were determined to be 0.612 and -2.97, respectively.

These observations and the above relationship may serve as a guide for further investigations in the catalytic behavior of other five-membered nitrogen heterocycles and their corresponding polymers, or to design a copolymer to demonstrate a certain type of bifunctional interaction.

Experimental Section

Potentiometric Titrations. The pK_a values were determined by differential potentiometric titrations[15] in 28.5% ethanol-water solution and an ionic strength of 0.02 M (Table III).

Table III. Dissociation Constants Determined by Differential Potentiometric Titrations[a]

Compd	pK_1	pK_2
1,2,4-Triazole	2.28	10.10
3-Methyl-1,2,4-triazole	2.95	10.85
3-Isopropyl-1,2,4-triazole	2.95	10.82
Poly-3-vinyl-1,2,4-triazole		11.00[b]
1,2,3-Triazole		9.50
4-Methyl-1,2,3-triazole		10.25
4-Isopropyl-1,2,3-triazole		10.25
1,2,3-Benzotriazole		8.65
4-Methylimidazole	7.40	

[a] In 28.5% ethanol-water, ionic strength, 0.02 M. [b] The correction factor n in pK_2 − pH = $n \log (1 - \alpha_2)/\alpha_2$ was determined to be 1.18 (A. Katchalsky and P. Spitnik, *J. Polym. Sci.*, **2**, 432 (1957)).

Kinetic measurements were done as previously reported.[2] Tris-(hydroxymethyl)aminomethane buffers, 0.02 M, and ionic strength 0.02 M, were employed at 26°. Appearance of 3-hydroxy-N-trimethylanilinium iodide was studied at 277 mμ below pH 8.50 and 293 mμ above pH 8.50.

3-Vinyl-1,2,4-triazole. 3-(β-Hydroxyethyl)-1,2,4-triazole[16] was mixed with preactivated molecular sieve A, prepared by heating the sieves in an oil bath at 280–300° for 2–3 hr under a reduced pressure of *ca.* 0.05–0.10 mm, in a flask equipped with a Dry Ice condenser. The flask was then immersed into a preheated oil bath (280–300°) and held at that temperature for 10 min. Pressure (0.5 mm) was then applied and the solid that formed on the condenser was freeze-dried to give 3-vinyl-1,2,4-triazole, mp 38–40°, 10–15% yield. 3-Vinyl-1,2,4-triazole decolorized $KMnO_4$ solution instantly, and gave a polymeric material on standing. Ir[9] showed vinyl absorption at 1660 cm^{-1}.

Anal. Calcd for $C_4H_5N_3$: C, 50.51; H, 5.30; N, 44.19. Found: C, 50.34; H, 5.34; N, 44.24, 44.31.

The nmr spectrum showed a typical ABC pattern for the vinyl group, with J_{AB} = 17.6 cps, J_{AC} = 10.5 cps, and J_{BC} = 2.0 cps. H_A at τ 3.72 was assigned to the proton attached to the α-carbon atom. H_B being *trans* to H_A absorbed at τ 3.77 while H_C being *cis* H_A gave a signal at τ 4.42. The proton attached to the ring carbon gave a peak at τ 1.74.

3-(β-Acetoxyethyl)-1,2,4-triazole. 3-(β-Hydroxyethyl)-1,2,4-triazole (5.8 g) in 30 ml of ethyl acetate was heated to reflux, then enough acetic anhydride was added slowly to bring the heterogeneous mixture into solution, and reflux was continued for another 10 min. The solvent was then removed under reduced pressure, and the residue was dissolved in 50 ml of ice–water and neutralized with sodium carbonate. After removal of the solvent under reduced pressure, the residue was extracted with chloroform. Chloroform was then removed under reduced pressure at room temperature. The residue was distilled under vacuum to give 3-(β-acetoxyethyl)-1,2,4-triazole, bp 160° (0.5 mm), 30–50% yield, $\bar{\nu}_{C=O}$ = 1750 and 1250 cm^{-1}.

Anal. Calcd for $C_5H_9N_3O_2$: C, 46.44; H, 5.79; N, 27.08. Found: C, 46.38; H, 5.79; N, 27.00.

Poly-3-vinyl-1,2,4-triazole. 3-(β-Acetoxyethyl)-1,2,4-triazole (1.0 g) was pyrolyzed in a distilling apparatus under reduced pressure (0.5 mm) at 180–200°. A mixture of 3-vinyl-1,2,4-triazole and starting material began to distill at 165°. The monomer, 3-vinyl-1,2,4-triazole, started to polymerize in the collection flask. The polymer which was contaminated with the starting material was purified in the following way: the mixture was extracted with absolute ethanol and the insoluble material was then dissolved in distilled water; the product was then reprecipitated with anhydrous acetone. This process was repeated six times. The polymer was finally dissolved in water and freeze-dried, mp 250°, 30% yield; $\bar{\nu}$ = 3200, 1650, 1090, and 1040 cm^{-1}. Poly-3-vinyl-1,2,4-triazole obtained in this way was shown to be identical with that obtained by polymerization of 3-vinyl-1,2,4-triazole on standing.

Anal. Calcd for $(C_4H_5N_3)_n$: C, 50.51; H, 5.30; N, 44.19. Found: C, 50.31; H, 5.30; N, 44.14.

3-Isopropyl-1,2,4-triazole. Diazotization of 5-amino-3-isopropyl-1,2,4-triazole, prepared by the method of Reilly and Drumm,[17] gave 3-isopropyl-1,2,4-triazole in 30% yield, mp 55–57°.

Anal. Calcd for $C_5H_9N_3$: C, 54.03; H, 8.16; N, 37.81. Found: C, 53.86; H, 8.10; N, 37.84.

4-Isopropyl-1,2,3-triazole. 4-Isopropyl-1,2,3-triazole was prepared by the procedure described by Hartzel and Benson,[18] bp 77° (0.5 mm), yield = 40%. The nmr in $CDCl_3$ showed signals at τ 9.10, (the isopropyl group, J = 7.0 cps), 7.35 (the methine hydrogen), 2.85 (the proton attached to the ring carbon), and −4.67 (the proton attached to the nitrogen atom).

Anal. Calcd for $C_5H_9N_3$: C, 54.03; H, 8.16; N, 37.81. Found: C, 54.07; H, 8.14; N, 37.83.

Acknowledgment. The authors are grateful to Dr. J. C. Salamone for his helpful discussions and invaluable assistance in composing this manuscript. Also, we gratefully acknowledge the financial support of the Research Laboratory, United States Army, Edgewood Arsenal, under Contract No. DAAA-15-67-C-0567, and the National Institutes of Health under Grant No. 2 RO1 GM 15256-02.

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